ERROR CORRECTION FOR VERTICAL SURVEYS CONDUCTED OVER A SUBSIDING LONGWALL MINING PANEL

by

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Abstract: The difference between a conventional land survey and a survey of subsiding ground is discussed and a correction method was formulated for surveys conducted on subsiding ground. The area over the longwall mining panel subsided detectible amounts during the time required to conduct the survey when subsidence was at its highest rate, which introduces error into the survey. When the ground subsides before the survey is completed, the survey no longer represents the locations of all points at a common point in time, which is a basic assumption of conventional land surveying. Conventional methods of correction average movement of subsiding points and apply those amounts of movement to points which were unaffected by subsidence, a different correction method was needed. A correction method was used which uses multiple surveys to calculate rates of subsidence for each point in the survey. Subsidence rates were used to estimate the location of each point at a common time. Results are presented using the correction for subsiding ground and using no correction. Different results of the same surveys are shown in terms of elevations and curvatures. The significance of the different types of corrections is discussed and the compounding of error is demonstrated when calculating curvatures.

Additional Key Words: Longwall Mining, Error Correction, Subside.

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Introduction

Mine subsidence is the product of a chain of events that begins several hundred feet below the surface of the ground and propagates upward. The end result is a subsidence trough. Strains caused by subsidence in the area of the trough is the direct cause of structural damage. An accurate, time efficient and cost-effective method of measuring the behavior of the trough is critical. Perhaps the most reliable and accepted method of monitoring mine subsidence is by the use of conventional surveying techniques. However, some modifications to the surveying procedure must be made when monitoring mine subsidence.

Survey Setup

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Multiple surveys were conducted over a longwall mining panel near West Frankfort in southern Illinois. Monitoring by surveying was started before the area began to subside, conducted at daily intervals during the peak subsidence and continued until subsidence had ceased. The area subsided between the months of May and August of 1990.

Soils of southern Illinois are typically highly expansive. To accurately measure subsidence, it was necessary to avoid measuring movements caused by other sources, such as freezing and thawing of the soil, and shrinking and swelling of the soil caused by changes in the moisture content. These types of movement occur most often near the surface.

Each survey monument had to be installed so that it would remain as stable as possible. A steel bar was isolated from the soil by surrounding it with sand. The sand allowed some movement near the surface while the bar remained in the ground below the freeze line (Figure 1).

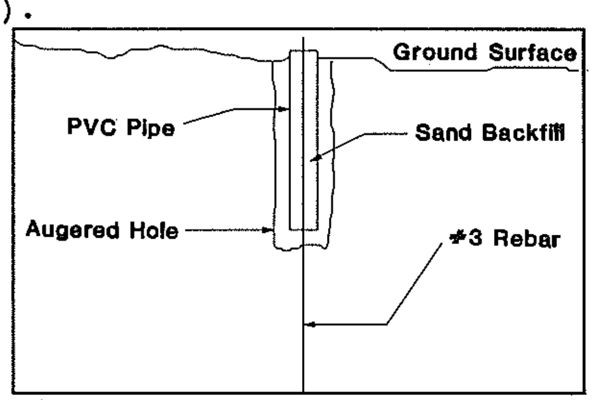

Figure 1. Survey Monument Construction.

The survey monuments were constructed of 1.5 m (5 ft), #3 steel reinforcing bar, 0.075 m (3 in.) O.D. PVC pipe, and sand. A 0.15 m (6 in) diameter hole was augered into the ground to a depth of about 0.5 m (1.5 ft). The reinforcing bar was then driven into the bottom of the hole until about 0.05 m (2 in) of the bar protruded above the surface of the ground. The PVC pipe was then placed in the hole around the bar and back-filled with tamped sand. The hole around the pipe was filled with tamped soil. The PVC pipe was then capped to isolate the sand from moisture. Lines of survey monuments were set up crossing and along the centerline of the subsidence trough. Shorter lines of monuments were also installed adjacent to test footings constructed on the center-line and on the edge of the subsidence trough.

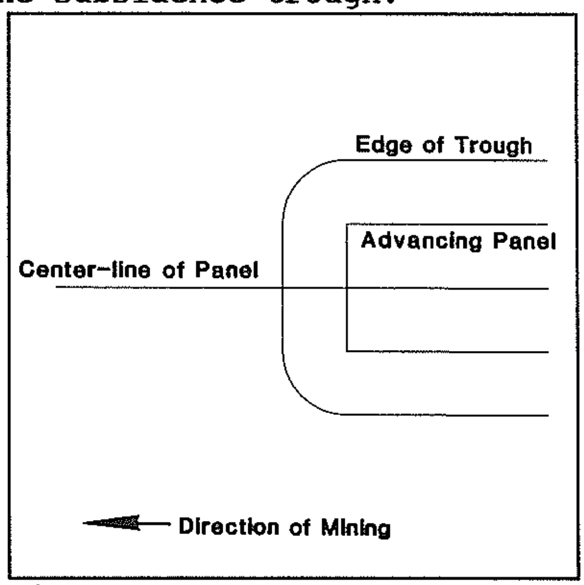

Figure 2. Layout of Survey Monuments.

To demonstrate the correction, a survey of fifteen monuments, numbered 1 through 15, located along the centerline of a subsiding longwall mining panel will be used (Figure 2). Level surveys were conducted on surveys used to demonstrate the correction method were conducted when the rate of subsidence was at its highest. Two surveys were conducted on the day which the maximum amount of subsidence occurred.

Vertical Survey

To obtain accurate measurements, a Pentax level with a micrometer accurate to 0.0001 m (0.0003 ft) was used with a Nedo temperature invariant leveling rod. The elevation of a point is determined by sighting the leveling rod through the optical level. The reading on the leveling rod indicates the elevation difference between the bottom of the leveling rod and the sights on the level. This is known because the optical level sights the leveling rod on the horizontal plane. Each time the level is set up, the operator back sights on a point of known elevation. Since the difference in elevation of the point of known elevation and the level can be determined, the elevation of any new measurement can be determined by finding the elevation difference between the level and the new point.

The initiation of subsidence was determined to be on May 10, 1990 and the end of subsidence was determined to be on August 8, 1990. The magnitude of subsidence was determined by subtracting the elevation of a given point before subsidence from the elevation of the same point after subsidence. The maximum amount of subsidence observed along the centerline was 1.425 m (4.674 ft). Over fifty percent of the total subsidence occurred in 5 days, when the subsidence rate was also at its greatest (Bennet et al).

Conventional Error Correction

Conventionally, when a survey is conducted, a loop is closed and a closure error is calculated. Closure error for a vertical survey is determined by measuring a series of elevations consecutively to create a loop. At some point, a point in the survey is used to calculate the elevation of a point which has already been surveyed. If the second measurement differs from the first, this is considered to be the amount of error in the survey loop. In a conventional survey, the total amount of error is then distributed evenly among all the points in the loop. For example, if a loop of ten survey points is determined to have a total error of 1 cm then each elevation in the loop would be adjusted by one tenth of a centimeter.

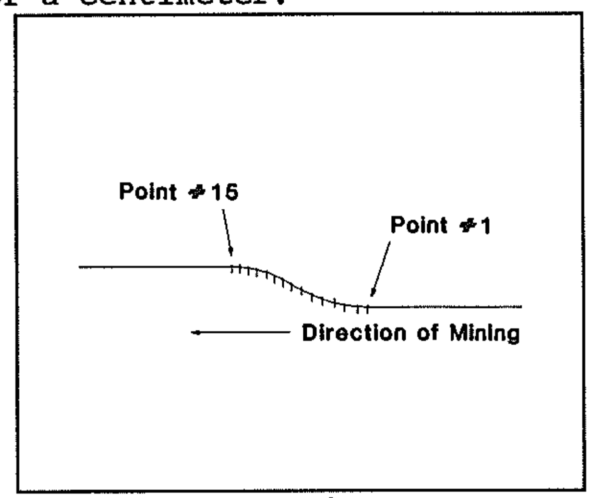

Figure 3. Subsidence Wave.

Typical Subsidence Surveys

One of the basic assumptions of conventional surveying is that all distances remain constant and any discrepancy is due to error or lack of precision. This is not always the case when surveying mine subsidence. Most published results of subsided mine surveys were begun at day 0 and continued for months or even years after the surface was undermined or collapsed. These surveys were conducted at monthly or weekly intervals. Since most surveys of subsided areas are started after subsidence has ceased, it is correct to use conventional error correction techniques. Surveys of subsided areas commonly apply no correction at all to the survey (Peng, 1992). In this project surveys were conducted either once or twice per day during the time of the maximum rate of subsidence. Subsidence occurred in measurable amounts during the two hours required to conduct the survey. Since the ground subsided before the loop could be closed, adjusting the distances would create more error than would be corrected.

It is possible to correct for subsidence that occurs during the survey, by obtaining rates of subsidence and simulating an instantaneous survey. A correction method was tested over the center line of an advancing longwall mining trough. Subsidence induced by longwall mining is the most convenient type of subsidence to monitor, because it is known when subsidence will begin in the area above the mine.

At its maximum rate, the ground surface over a longwall mining panel can subside at about 1 cm (2.5 in) per hour (Table 1). The rate of subsidence depends on the position of a given point on the subsidence wave (Figure 3).

The problem with calculating closure error of a subsiding surface is that the survey cannot be completed before the ground moves. Closure error could be calculated on a subsiding surface only if an instantaneous survey is conducted. Since this is impractical, if not impossible with current technology, the only logical alternative is to simulate an instantaneous survey.

If a line of points is surveyed, it takes some finite period of time to conduct the survey. That finite period of time is the difference between the initial time , when the first measurement is recorded, and the final time when the final measurement is taken.

In order to know precisely what the profile shape is, one would need to know what the profile is at an instant in time. As the survey is conducted, the survey monuments subside from the initial instantaneous profile to the final instantaneous profile. The problem is that the survey spanned a finite time period and does not represent either of the true subsidence profiles.

An instantaneous profile can be simulated by calculating a rate of subsidence for every point on the survey. After the subsidence rates are calculated, all points can be projected forward or backward in time (Table 1).

Table 1. Comparison of Actual and Corrected Profiles

Point	5-23-90 AM Elev. Drop (m)	AM Time of Measure	5/23/90 PM Elev. Drop (m)	PM Time of Measure	AM/PM Delta Elev. (m)	Subsidence Rate (m/hr)
1	0.737	8:00	0.820	4:00	0.083	0.01038
2	0.667	8:04	0.756	4:04	0.089	0.01113
3	0.598	8:08	0.687	4:08	0.089	0.01113
4	0.571	8:12	0.659	4:12	0.088	0.01110
5	0.541	8:16	0.630	4:16	0.089	0.01113
6	0.515	8:20	0.601	4:20	0.086	0.01075
7	0.487	8:24	0.572	4:24	0.085	0.01063
8	0.458	8:28	0.540	4:28	0.082	0.01025
9	0.435	8:32	0.516	4:32	0.081	0.01013
10	0.409	8:36	0.487	4:36	0.078	0.00975
11	0.383	8:40	0.458	4:40	0.075	0.00938
12	0.361	8:44	0.434	4:44	0.073	0.00913
13	0.334	8:48	0.404	4:48	0.070	0.00875
14	0.278	8:52	0.340	4:52	0.062	0.00775
15	0.221	8:56	0.273	4:56	0.052	0.00650

One foreseeable source of error would be a change in subsidence rate during the time taken to conduct the survey. For this reason loops should be arranged so that completion can be achieved within as short a time span as possible.

To calculate subsidence rates in the field, the elevation of each point must be measured twice. Two surveys should be conducted on each loop with the time of each measurement also recorded. The measurement of the first point is taken at the initial time, t_1, the second at t_2, the third at t_3, etc. With two different elevations for each point at two different times, the data can be used to calculate the subsidence rate for each point. Figure 4 plots projected data points shown with the two sets of actual data used to calculate the subsidence rates. The surveys were conducted approximately eight hours apart. An eight-hour interval was used because this was the smallest interval available. Ideally one would want two surveys conducted about an hour apart to insure that the subsidence rates were relatively the same.

Figure 5 compares the curvature of the actual profiles of points 1 to 15 with the corrected profiles of the same points.

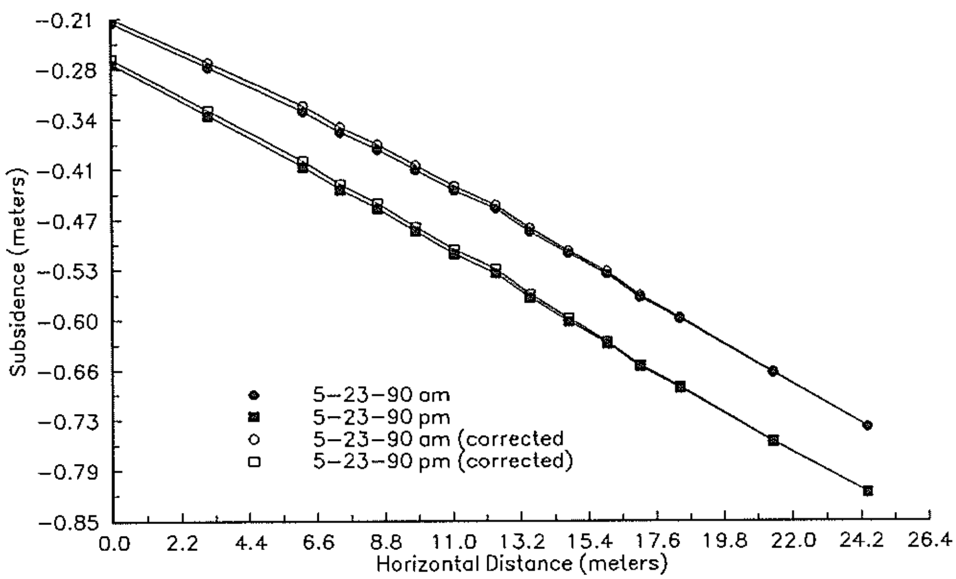

Figure 4. Actual and Corrected Profiles

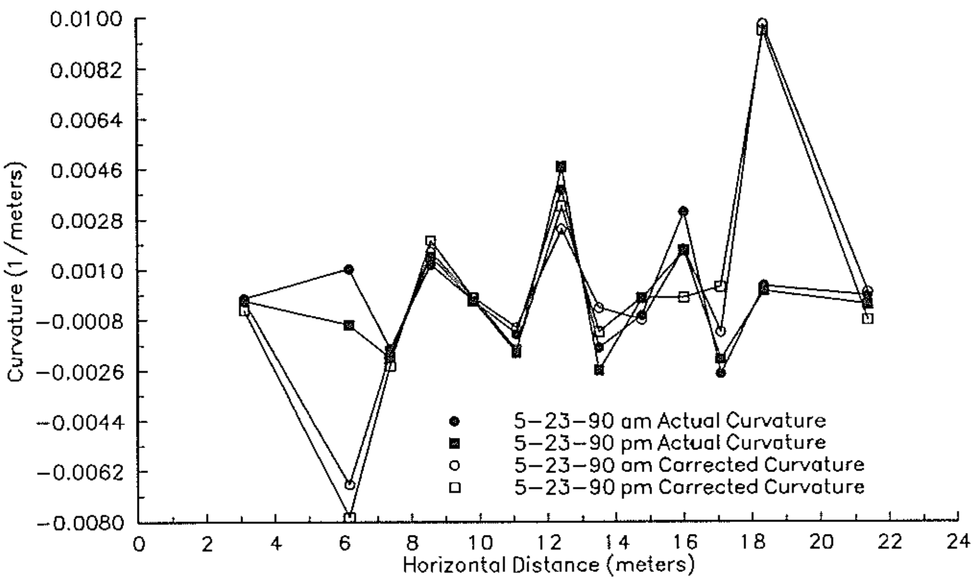

Figure 5. Actual and Corrected Curvatures

Table 2. Comparison of Actual and Corrected Curvatures

Point	AM/PM Correction	AM Corrected Elevation (m)	PM Corrected Elevation (m)	AM Curve 1/(m)	PM Curve 1/(m)
1	0.0000	0.7370	0.8200		
2	0.0008	0.6662	0.7552	-0.0002	-0.0008
3	0.0015	0.5965	0.6855	-0.0007	-0.0095
4	0.0022	0.5688	0.6568	-0.00012	0.0004
5	0.0030	0.5380	0.6270	0.00017	0.0000
6	0.0036	0.5114	0.5974	-0.0008	0.0000
7	0.0042	0.4828	0.5678	-0.0004	-0.0012
8	0.0048	0.4532	0.5352	0.0024	0.0033
9	0.0055	0.4295	0.5105	-0.0011	-0.0019
10	0.0058	0.4032	0.4812	0.0000	0.0000
11	0.0062	0.3768	0.4518	0.0016	0.0020
12	0.0067	0.3543	0.4273	-0.0020	-0.0024
13	0.0070	0.3270	0.3970	-0.0067	-0.0079
14	0.0067	0.2713	0.3333	-0.0001	-0.0005
15	0.0061	0.2149	0.2669		

The differences in curvature are substantial. Since the correction adjusts each point according to the time that elapses after the first measurement is taken, one end of the survey line is adjusted more than the other (Figure 4). The first point required no adjustment. This is the most significant aspect of this correction method. If the correction only shifted the whole line some uniform distance as done with closure correction, then it would be trivial. Since the correction is nonuniform, it deserves more attention.

Conclusions

It appears that the calculation of closure error is of little significance compared to the correction from projecting the points to time t_1. A plot of the points after calculation of closure error is indistinguishable from that of the projected points. Since the rate of subsidence can vary significantly over short horizontal distances, i.e. distances of 5 m (16 ft) or less, the survey should be conducted as quickly as possible, regardless of the correction method used.

In most cases, the most precise methods and equipment for surveying are used to monitor mine subsidence. Greater than normal care is taken to conduct the surveys required to monitor mine subsidence. A monitoring method which produces more accurate results would be beneficial. Since the profile which most nearly represents an instantaneous survey of the subsiding area is desired, this correction method should de used for surveys which have detectable amounts of movement taking place during the survey.

This method would be useful for measurement of any subsiding area or structure which subsides at a rate which would introduce measurable amounts of subsidence before the survey could be conducted. When the survey data is intended to be used for calculation of curvatures or other properties which involve the multiplication of error, the correction has the greatest significance.

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